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NAVAL POSTGRADUATE SCHOOL
Monterey, California

TNT07 MIO San Francisco Bay, Atmospheric Effects
After Action Report

by

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12 October 2007

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13. ABSTRACT

The authors participated in four Tactical Network Topology Marine Interdiction Operations (TNT MIOs) during FY 2007. The overall goals of the authors TNT MIO studies were (1) to provide military and law enforcement personnel with real time and future information on how the environment will affect marine interdiction operations and (2) to develop, verify and improve models and procedures used in (1) by comparing predictions with actual in situ observations.

Similar to earlier TNT MIO experiments, the authors addressed how environmental factors affect the transmission of radiation in the visible and radio bands of the electromagnetic spectrum. But, unlike the earlier experiments, more emphasis was placed on other environmental effects such as winds, sea state, tides and other weather factors. By developing a system to provide the relevant personnel with this information we hope to (1) enhance overall situational awareness, (2) enhance mission planning and safety and (3) provide an advantage over any potential adversaries who might not consider these atmospheric effects.

For this project we made *in situ* measurements of atmospheric conditions as and also incorporated a large amount of “outside” information to give a better picture of the environmental conditions that affected the MIO. In addition to providing weather briefings in the mornings of the operations, several environmental products were made available via the experimental networks. These products included results of visibility and radar range model predictions developed especially for these experiments as well as more general products downloaded from the World Wide Web. The data collection efforts were successful and allowed verification and improvement of the effects models.

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EXECUTIVE SUMMARY

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I. BACKGROUND

This report investigates how the environment affects marine interdiction operations. In particular, the authors describe and analyze results from the most recent Tactical Network Topology (TNT) Maritime Interdiction Operation (MIO) field programs which occurred in FY 2007. Four field programs are addressed in this report (Table 1).

Table 1 TNT MIO Field Programs in FY 2007

Name	Measurement Period
TNT07-1 MIO	30 November – 1 December 2006
TNT07-2 MIO	20 March – 21 March 2007
TNT07-3 MIO	5 June – 6 June 2007
TNT07-4 MIO	11 September – 13 September 2007

The authors performed measurements in the San Francisco Bay and provided environmental products for several daylight hours during the days listed in Table 1. Measurement equipment setup occurred on the day before the first measurement day for all four field programs.

The overall goals of our TNT MIO studies are

(1) To provide military and law enforcement personnel with real time and future information on how the environment will affect marine interdiction operations.

(2) To develop, verify and improve models and procedures used in (1) by comparing predictions with actual in situ observations.

In previous years, our primary focus was on how the atmosphere affects electromagnetic (EM) propagation, in particular the detection of targets such as vessels, personnel and weapons using optical (human eye and binoculars) and radio frequency (radar) sensors. During FY 2007, we continued this focus, but also placed more emphasis on other environmental factors that affect marine interdiction operations such as wind and wave effects, tides and swell interaction and weather events. By understanding these environmental effects, our security forces can use this information as a force multiplier to enhance the effectiveness and safety of marine interdiction missions.

Central to Goal (1) is the ability to transmit environmental information to and from interdiction vessels and command centers. This was accomplished by the TNT network systems that were in place during the field programs (Figure 1). Note that the blue squares in Figure 1 could simplistically represent the flow of information for many of the various experiments that were carried out by various groups during the TNT MIO exercises. In these cases, the information flows between field personnel and command centers and off site experts and models within the TNT framework. What is different about the flow of environmental data from some other types of TNT MIO data is that the World Wide Web (WWW) plays a vital role, as indicated by the red square in Figure 1. The WWW represents a vast resource of information on real time conditions from nearby stations and predictions of future conditions from forecasters and models.

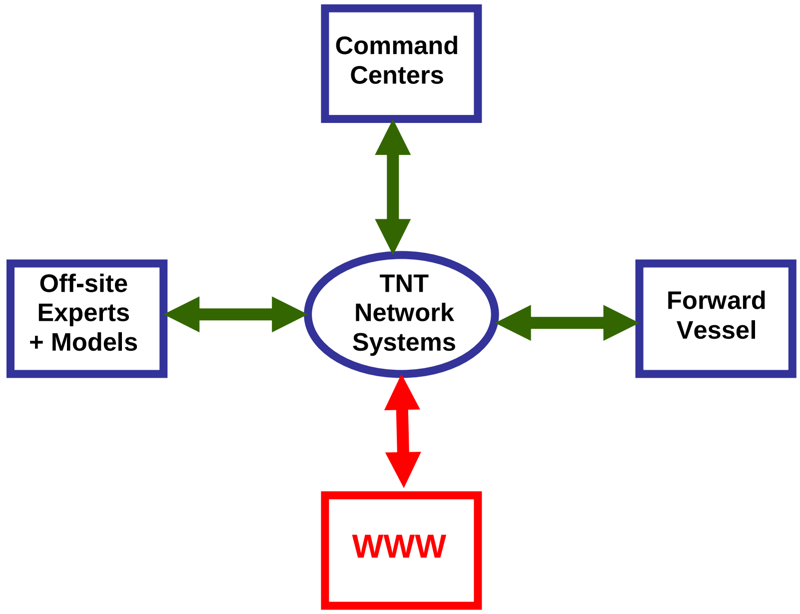

Figure 1. Simplistic diagram showing the flow of environmental information during the TNT MIO field programs. The forward vessel transmits the met station data and receives environmental information from the outside world. Similar to other TNT experiments, the information flow goes to and from human experts and model simulations within the TNT framework (blue frames). Unlike some of the other experiments, the WWW (red) represents an essential source of information for environmental data.

The approach to our efforts in satisfying Goal 1 was to use various data sources to create environmental data sets. Some of these data are used directly for operational products while other data are used as inputs into effects models (Figure 2). The outputs from the effects models and the direct data are then displayed graphically and made available to the field personnel and commanders via the TNT network using the Groove software in real time during the various field exercises. Dr. Guest also used the raw data sources to prepare a weather brief that was presented at the start of each day during the TNT MIO 07-3 and TNT MIO 07-4 field programs.

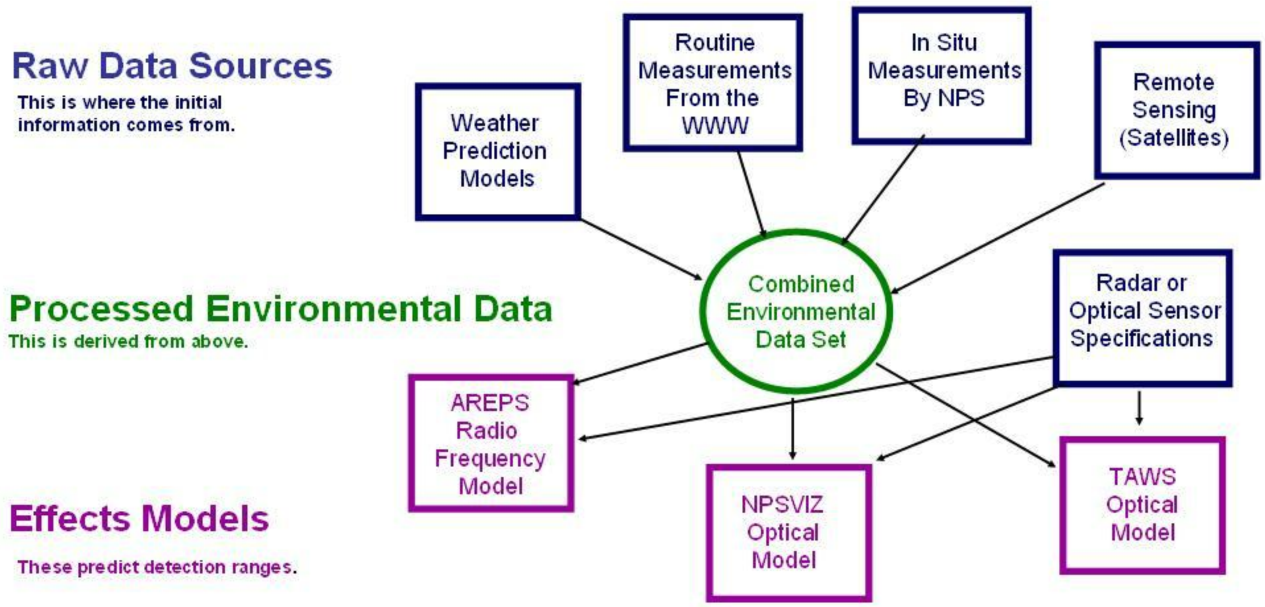

Figure 2. General data flow diagram showing the relationships between the raw data sources, the environmental data and the effects models. The output from the effects models and direct products from the raw data are then used to create the graphical products that are made available to commanders and field personnel.

Goal 2 involved comparison of the model predictions with observations made during the field programs. Quantitative comparisons primarily concerned the visibility predictions while qualitative comparisons were made between the weather forecasts in the morning and the actual conditions later in the day. These will be described in detail later.

The raw data sources, processed environmental data, effects models and output products are described in more detail in Section II. Next in Section III are the results of this procedure and a discussion of the model verification measurements. Examples of the products that were produced are interspersed throughout the report. Finally the lessons learned and future plans are presented in Section IV. The Appendix provides background information on radar and optical target detection.

II. SCOPE OF EXPERIMENT

A. RAW DATA SOURCES

1. Introduction to Raw Data Sources

The four types of raw data sources shown in Figure 2 are

(1) In situ measurements
(2) Weather prediction models (WWW)
(3) Routine measurements (WWW)
(4) Remotes sensing (Satellites) (WWW)

Source (1) can be further separated into three components, the first of which is processed in real time while the other two are processed and analyzed in later days and weeks:

- the surface met system deployed on the Alameda County Sheriffs Boat (ACSB)
- the visibility observations performed by Dr. Guest while on the ACSB
- information obtained from conversations by Dr. Guest with law enforcement and military personnel concerning their experiences on how the environment affects their ability to detect targets and other aspects of marine interdiction operations

Sources (2), (3) and (4) were all obtained from the WWW either by Ms. Jordan in the CENTRIX lab at NPS or by Dr. Guest via his personal computer in his hotel room, the TOC at the Yerba Buena Coast Guard station or while on board the ACSB. Each component of Source (1) is described in separate subsection below while Sources (2), (3) and (4) are described in a single subsection.

2. Surface Met System

We deployed a meteorological instrument suite on the boarding vessel for several hours during all the days listed in Table 1. This suite consisted of a pole mounted on the central tower frame of the vessel with instruments attached to measure air temperature, sea surface temperature (SST), humidity, wind vector, compass heading and GPS position (Figures 3, 4 and 5).

The purpose of these met station measurements was to provide measurements that can be used to predict or understand

1. optical turbulence that affects visible detection,
2. evaporation duct characteristics that affect radar and communications,.
3. the direction of a potential toxic plume,
4. the forcing of wind waves, sea spray, aerosol generation and other environmental parameters
5. the verification of the weather forecasts provided online and by Dr. Guest in the morning weather briefings.

We used the compass heading and GPS position to calculate ship orientation and movement which is required to get the true wind vector because the wind sensor can only measure winds relative to the ship platform. Previous reports (e.g. Guest et al., 2006) describe the various instruments and their accuracies and other specifications.

Figure 3. Photograph of the Alameda County Sheriffs Boat (ACSB), the location of the ship met station during the TNT 07-3 MIO. The met station itself does not clearly stand out, but it is possible to see the sonic anemometer just to the left of the red indicator line. This was the same location used in the other FY 2007 TNT MIO programs.

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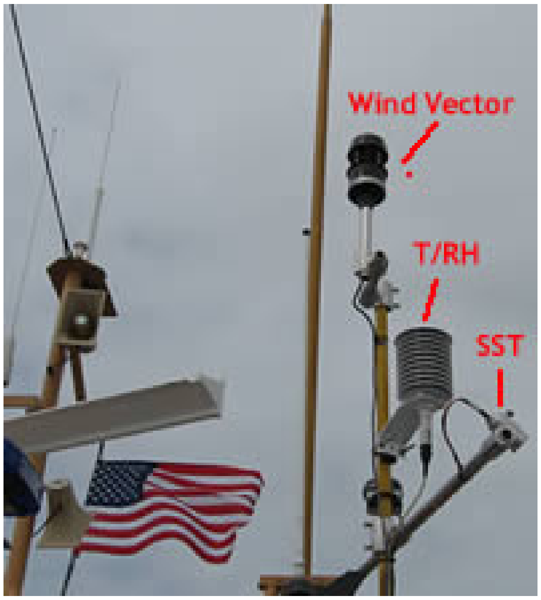

Figure 4. Photograph of the met station showing the environmental instruments aboard the Alameda County Sheriffs boat during TNT 07-2 MIO. Shown are the instruments to measure wind vector, temperature and humidity (T/RH) and sea surface temperature (SST). There is also a GPS sensor (not visible) A pressure sensor was located in a weatherproof electronic box which was deployed at the base of the met tower just below the area shown in the photograph. The equipment suite and placement shown here was very similar to the setup during the TNT 07-1 MIO and TNT 07-3 MIO programs.

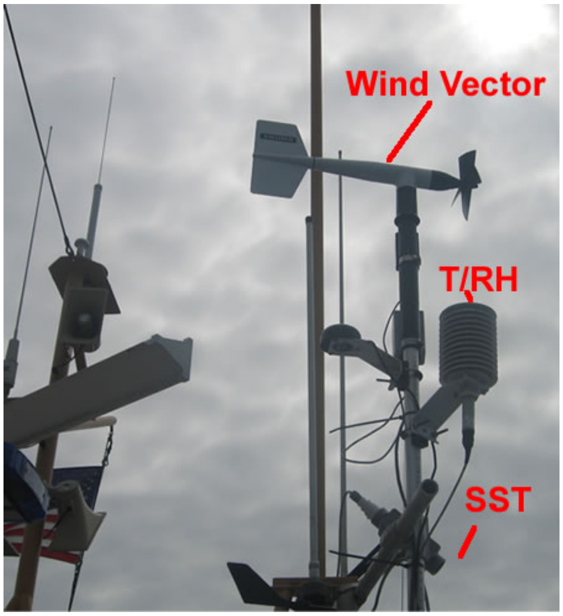

Figure 5. Photograph of the met station showing the environmental instruments aboard the Alameda County Sheriffs boat during TNT 07-4 MIO. These are similar to previous experiments except that the wind vector was measured with a propeller anemometer.

For TNT 07-4 MIO we replaced the sonic anemometer relative wind speed measurement with an R.M Young propeller anemometer (Figure 5). This was because the sonic anemometers have had a high failure rate in other projects and were deemed unreliable by the authors.

Another change in the instrumentation used during TNT 07-4 MIO was the substitution of the previous SST IR probe with a higher quality and more accurate sensor manufactured by the Heitronics Corporation, the KT-19 model. For all of the FY 2007 TNT MIO projects we also used alcohol and digital thermometers to perform occasional measurements of SST directly; this involved collecting a water sample with a small bucket and putting the thermometer into the bucket. This was used as a check of the remote continuous IR SST measurements on the met station.

3. Visible Target Detection Range Estimates

During each of the days during the FY 2007 TNT MIO programs, Dr. Guest performed various types of visibility measurements on board the Alameda County Sheriffs Boat. The measurements involved detecting features on various targets using naked eye, 8 power field binoculars, 8 power gyro-stabilized binoculars and a compact digital camera. Most of observed features were on the "official" target vessel that was used for that particular MIO (Figures 6 and 7). In addition, Dr. Guest recorded maximum visibility ranges (for any size object) using distant objects such as buildings, loading cranes and mountains. A standard bar chart was displayed on some of the various vessels to estimate visibility ranges, but this was often logistically challenging due to the often changing positions and orientations of the vessels in the TNT MIO programs. It was found that many more useful visibility estimates could be obtained by using features on the targets vessels that were easy to observe from different angles such as “Old Glory” (Table 2).

Figure 6. The target vessel *Clean Bay II* which was used in TNT 07-3 MIO. The “Old Glory” on the mast behind the bridge was a useful feature. Ranges were recorded when the flag was first seen (but no features on it) when the stripes were distinct and when the starts were visible using the naked eye and binoculars. Other features that were observed were the lettering on the bow, the bridge windows, a sign on the side (not seen here, see Figures 8 and 9) and people.

Figure 7. The target vessel *Pacific Responder* which was used in TNT 07-2 MIO. Features observed on this vessel were the bow lettering, the bow mast, the bridge windows, the life boat and the “Old Glory” (not visible in this photograph).

Table 2. Various Target Features for Which Maximum Visibility Range Was Detected

Target Feature	Smallest Dimension Size	Comments
Various Vessel Antennae	1 – 3 cm	
Stars on “Old Glory”	2 cm	
Cell phones	3 cm	Surrogate for small hand weapon
Vessel Railings	2-6 cm	
Stripes on “Old Glory”	4 cm	
Lettering on Vessel Signs	3-20 cm	
Towers on Vessels	5-40 cm	
Standard Bar Chart Bars	10 cm	
Bow Lettering	20-50 cm	
People	40 cm	Modeled in real time
Vessel Cranes	50 – 90 cm	
Vessel Windows	0.5 – 2 m	
Entire Standard Bar Chart	2 m	
Life Boats	3 m	
Entire Vessels	10-500 m	Target ship too close, others used
Buildings, Bridges	100 – 1000 m	Used to estimate maximum visibility
Mountains	> 1 km	Used to estimate maximum visibility

Figures 8 and 9 show an example of how the resolution at various ranges was estimated. The close up image reveals a variety of lettering sizes. As this sign was observed at greater ranges various features on the sign could no longer be distinguished until at a range of about 3 km (Figure 9) only the sign itself and general letter blocks could be distinguished on the photograph. Similar observations were made using the other features listed in Table 2. The examples shown here are based on photographs, most observations were undertaken using the naked eye and binoculars and recorded in a notebook. The results of these measurements are discussed in Section 3.

Figure 8. Sign on the target vessel *Clean Bay II.* This was at a close enough range that the camera resolution was about 0.2 cm.

Figure 9. The same sign shown in Figure 9 but at a much further range. on the target vessel *Clean Bay II.* The camera resolution was about 3 cm.

4. Publicly-Available Meteorological Data

To get a better overall picture of the atmospheric conditions that might affect interdiction operations and to include in the morning weather briefs (TNT 07-3 MIO and TNT 07-4 MIO), a variety of publicly-available products were downloaded from the web. These products included:

1. Text forecasts and detailed weather discussion from the National Weather Service (NWS) for San Francisco (SF) and Oakland
2. Weather observations for various SF Bay locations in text and graphical format
3. Visibility observations from the SF and Oakland airports, updated every hour.
4. Radiosonde profiles from Oakland airport in text and graphical format, every 12 hours.
5. Map of wind speed and direction in the SF Bay area based on a model developed by Dr. Wendall Nuss, Department of Meteorology, NPS and also another product produced by the US Coast Guard.
6. Visible and IR satellite images (grey shades) of the SF bay area every 30 minutes from a geostationary GOES satellite.
7. True color visible images from polar orbiting MODIS satellite, one or twice per day.

Similar, but not so detailed products were also produced for the Sweden and Singapore areas and for the New York Harbor (the latter for TNT07-4 MIO) in support of the TNT "outside" collaborators. For each of these regions, Ms. Jordan created web pages and/or WORD documents that contained lists of relevant links. An example of this list of links (the one used during TNT 07-3) is shown on the next two pages (Figure 10). Products that were deemed important to the interdiction operations on a particular day were put on the TNT Groove network, if possible. For this report, the authors will not show all these products although the reader can follow the links on electronic version of this report. Some of the products will be displayed in Section III.

Department of Meteorology
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Weather Support for TNT 07-3

Satellite

WCoast 1-km Visible GOES (NWS)	SF Bay 1-km Visible GOES (NRL)	WCoast 2-km IR GOES (NWS)	MODIS 250m Visible only if current

NOGAPS and COAMPS Forecast Models

FNMOC	NOGAPS & Satellite

Regional Observations

Current SFC Plot	Obs (Text)	Wind Analysis	Wind Profiler

Point Observations and Forecasts

San Francisco	Observations	Observations (text)	Forecast
Oakland	Observations	Observations (text)	Forecast

SST	NCDC Buoy 46026 37.75 N 122.82 W 37°45'32" N 122°50'00" W	SF Golden Gate Bridge (9414290) 37° 48.4'N 122° 27.9'W	Alameda Pier 3 (9414750) 37° 46.3'N 122° 17.9'W

Refractive Index Plots

Oakland, CA - 00Z 37.73N 122.22W 3m	0-1600m Plot	0-10km M & N Plot	Skew-T and Winds
Oakland, CA - 12Z 37.73N 122.22W 3m	0-1600m Plot	0-10km M & N Plot	Skew-T and Winds
Vandenberg AFB - 00Z 34.65N 120.57W 112m	0-1600m Plot	0-10km M & N Plot	Skew-T and Winds
Vandenberg AFB - 12Z 34.65N 120.57W 112m	0-1600m Plot	0-10km M & N Plot	Skew-T and Winds

Decode METAR	Decode METAR (PDF)	C to F Conversion

Singapore Synoptic Charts and Refractive Index Plots

Synoptic Analysis and Forecast Charts

Singapore Meteorological Service	Satellite Menu	Current Station Observations
GOES-9 IR Satellite - 0030 UTC	GOES-9 IR Satellite - 0830 UTC	Select IR Image

Refractive Index Plots from Singapore Sounding

Singapore - 00Z 1.37N 103.98E 16m	0-1600m Plot	0-10km M & N Plot	Skew-T and Winds
Singapore - 09Z 1.37N 103.98E 16m	0-1600m Plot	0-10km M & N Plot	Skew-T and Winds

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European Synoptic Charts and Refractive Index Plots

Synoptic Analysis and Forecast Charts

METEOSAT IR Satellite - Latest	Satellite Menu

Refractive Index Plots from European Soundings

Visby, Sweden - 00Z 57.65N 18.35E 47m	0-1600m Plot	0-10km M & N Plot	Skew-T and Winds
Visby, Sweden - 12Z 57.65N 18.35E 47m	0-1600m Plot	0-10km M & N Plot	Skew-T and Winds

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Figure 10 (includes previous page). Web page and WORD document used in support of TNT 07-3 MIO. Similar web pages were created for the other experiments including links to the New York harbor areas for TNT 07-4 MIO. .

5. Informal Discussions with Various Participants

While on the boarding vessel, Dr. Guest informally interviewed the boat operators (Alameda County deputies) to determine what factors are most important to them for detection of various targets and suspicious actions. We also discussed with the deputies and others involved in the boarding operations how various weather events such as strong winds and precipitation would affect their ability to carry out MIO type operations. These conversations provided important feedback that helped us identify the most important environmental factors for the personnel in the field tasked with undertaking boarding operations. These results are discussed in Section III.

B. DATA PROCESSING

1. Real Time (i.e. current) Data

The met station data processing for the FY 2007 TNT MIO experiments was similar to the previous year. Three systems were involved on the boarding vessel: a Campbell Scientific data logger, a "data collection" laptop and a "data processing and display" laptop. The data logger was located in a sealed box outside on the flying bridge while the laptops were inside the main bridge. The data logger queried the met tower sensors every second, converted the data from engineering to scientific units and saved 5 second interval data which were transmitted via cable to the data collection laptop. This computer then calculated 5 minute averages of the data, performing vector averages of the true wind speed and direction. These 5 minute data were then transferred to the data processing and display laptop and were used as is (for real time weather information) and also as input into the effects models. These basic meteorological data and the results from the effects model were plotted on the display of the latter computer (see examples below). This information was also put on the TNT network via the Groove software whenever possible.

2. Post-processing

The primary post-processing task involved the visibility observations that were originally contained in hand-written notes. These were quality-checked and uploaded for analysis. We also checked the quality of the met data more carefully than was possible during the exercises and uploaded the photographs along with supporting information on times, locations and other notes about the photographs. The quality and accuracy of all the real time model and web products were also checked afterward.

C. EFFECTS MODELS

Three models related to target detection were run by the authors in real time during all the FY 2007 TNT MIO experiments. These were

1. NPS Visibility Model (NPSVIZ)
2. Target Acquisition Weapons Software (TAWS)
3. Advanced Refraction Effects Prediction System (AREPS)

1. NPSVIZ

The NPSVIZ model was developed by Dr Guest and includes the effects of optical turbulence, atmospheric extinction and scattering (aerosol, haze, precipitation) and sensor resolution (including eyeball resolution). The optical turbulence part of the model is based on surface layer theory and involves several iterative steps to estimate the magnitude of the optical turbulence parameter, C_N^2. The other model physics are relatively simple, basically just single terms in a range estimate equation for each size target. For extinction and scattering effects we used the in situ total visibility observations or airport-reported visibility range if the former were not available. Eventually more sophisticated prediction models of aerosols could be included so that these effects could be forecasted rather than just based on current observations. The current version of NPSVIZ does not include non-atmospheric effects such as target background, lighting conditions and the effect of a rolling ship on binocular performance. A strength of the model is that it can produce automatically in real time a series of visibility estimates for various features which can then be posted on the TNT networks for immediate use by field personnel and commanders (Figure 11). The model also provides a conceptual framework for understanding in what situations the atmosphere will play an important role in target detection. The NPSVIZ model was run on Dr. Guest's laptop computer on the sheriff's boat and the results were posted on the TNT network via Groove from there

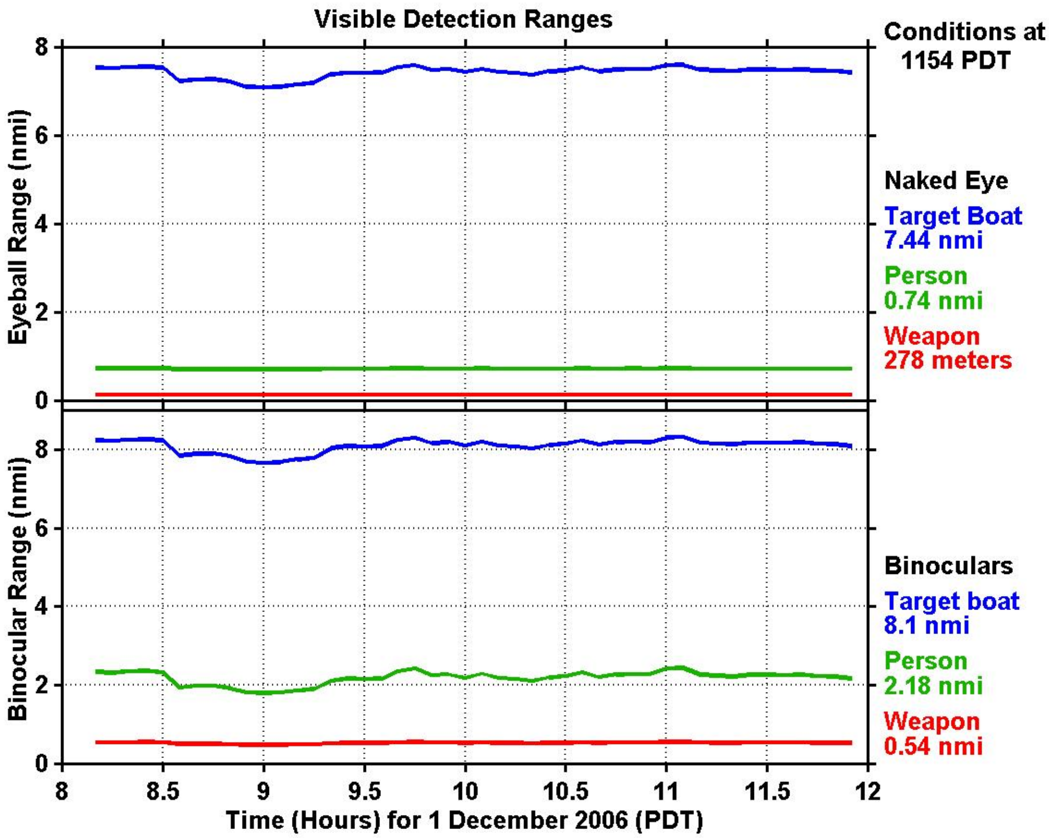

Figure 11 Example of NPSVIZ output used during the TNT MIO projects (in this case TNT 07-1 MIO). The results are presented as a time series for the three types of targets using the naked eye (top plot) and normal 8X binoculars (bottom plot). In this case there was a haze present that limited visibility ranges to about 8 km. For this reason, binoculars improved detection ranges for small, close objects but did not increase the detection ranges for larger distant objects due to the haze.

2. TAWS

TAWS is a sophisticated target detection software package that was developed by the Air Force Research Laboratory, the Navy SPAWAR Systems Center, the Navy Research Laboratory, the Army Research Laboratory, the Army Topographic Engineering Center, the Air Force Weather Agency and the Coast Guard R&D Center. This model uses a variety of environmental, sensor, target and mission parameters to produce a several products. These parameters can be based on real time measurements or predictions. The TAWS product used in support of TNT MIO was the target range estimates as a function of viewing direction (Figure 12). Running the model requires several minutes and requires a fair amount of user interaction for each model run. For this reason it was not practical to produce time series of TAWS range predictions. Instead TAWS was run once each morning of the field programs by Ms. Jordan at NPS based on expected conditions for the day.

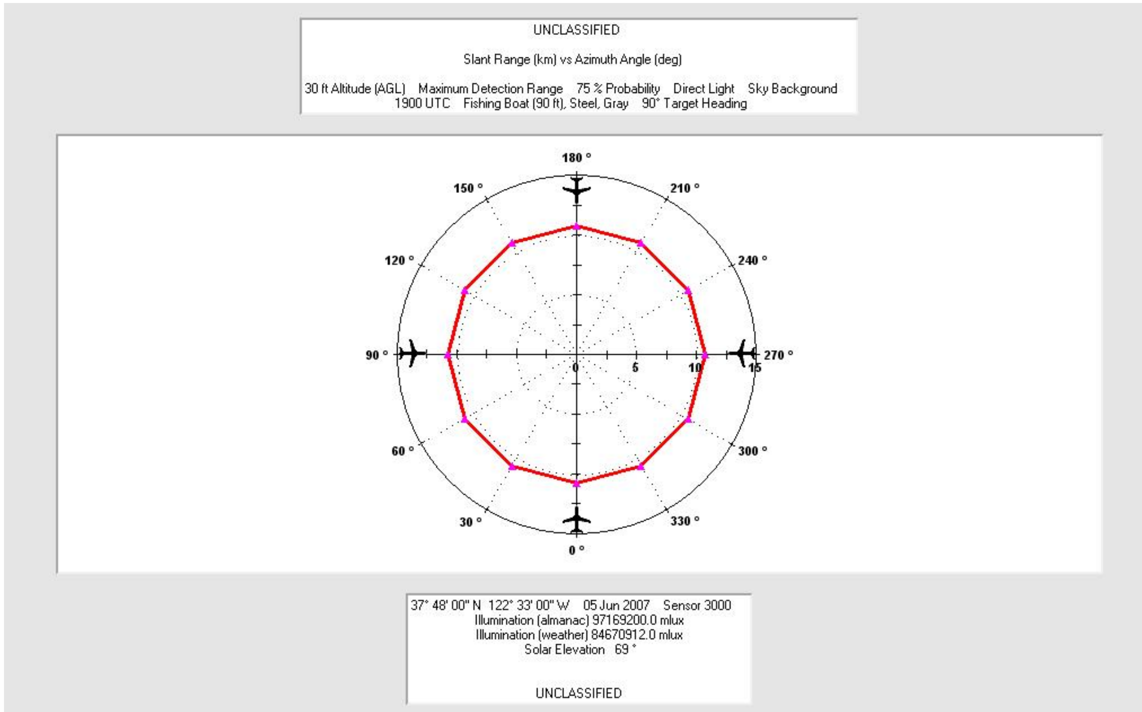

Figure 12 Example of TAWS output used during the TNT MIO projects. This was for visible (television) detection of a small boat. The results are plotted in spherical coordinates so that the distance of the red line from the origin represents the predicted range from various approach angles. In this case each tic mark represents2.5 km so that the predicted detection ranges were about 10 km. In this situation the backgrounds from each angle were assumed to be the same, the sky was overcast and the ship was assumed to look the same from each angle, so there is no angle dependency. But when the sun is visible, the background is different or target orientation is important then the red line will not be symmetrical. This figure, as displayed here, is somewhat unclear, the actual products were easier to see. Similar plots were produced for IR sensors; this would be important for nighttime operations (which did not occur in the TNT MIOs).

3. AREPS

AREPS is a radio frequency (rf) range prediction software package developed by SPAWARS San Diego. For TNT it was applied to radar detection ranges. The model requires a profile of atmospheric humidity and temperature. These were obtained using the latest Oakland airport radiosonde sounding data. The model also requires radar and target specifications, for these, generic representations of typical TNT MIO uses were used. This model was run by Ms. Jordan at NPS during the first three TNT MIOs in FY 2007 and by Dr. Guest on site for the TNT 07-4 MIO. Earlier reports describe AREPS in more detail. Two types of products were produced, radar range as a function of height for a particular bearing (Figure 13) and radar range at a particular height for various bearings (Figure 14). Similar to TAWS, AREPS requires significant human interaction and is therefore not suited for automatic forecasts. AREPS was typically run in the morning of each day during the FY 2007 TNT MIO experiments.

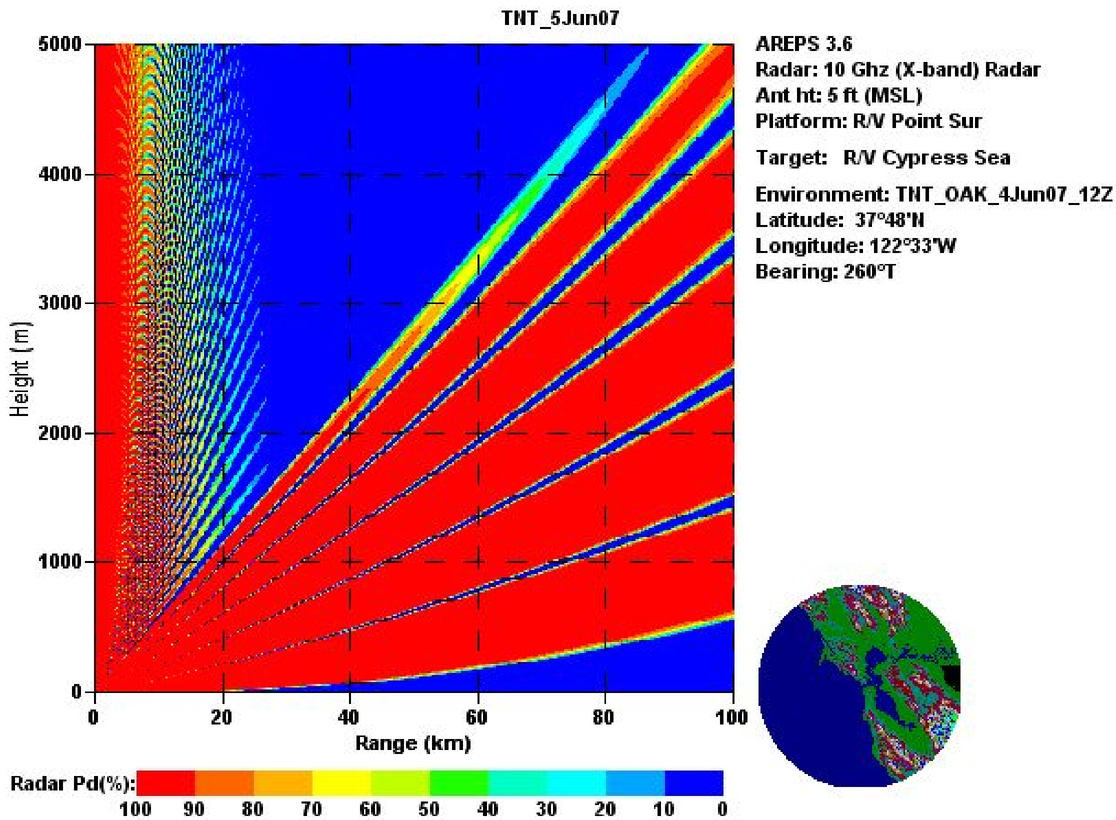

Figure 13 Example of AREPS range vs. height diagram showing probability of detection (pd) contours.

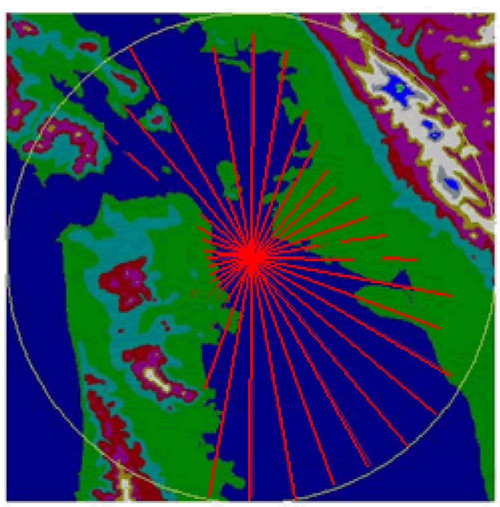

Figure 14 Example of AREPS range vs. bearing diagram for a vessel near Yerba Buena Island. Each "spoke" represents the 90% probability of detection range for a small boat target from a radar 12 ft height, similar to the radars on the Alameda County Sheriff's boat.

III. RESULTS OF EXPERIMENT

A. RESULTS INTRODUCTION

We were able to perform all the meteorological measurements and model runs discussed above. In this section we will present the results and more examples of the products that were made available during the FY2007 TNT MIO experiments. This section begins with a general description of the weather conditions for each of the experiments. This is followed by a presentation of the visibility observations and forecasts, the radar detection predictions, TNT connectivity issues and results from the discussions with operational personnel.

B. GENERAL METEOROLOGICAL AND VISIBILITY CONDITIONS AFFECTING MIO OPERATIONS AND INSTRUMENT PERFORMANCE

1. TNT07-1 MIO

The main field program occurred on two days 30 November and 1 December, 2006. Meteorological conditions for both days of the main field program in the San Francisco Bay were benign and clear (Figure 15). Winds were light and sea state was almost flat. Haze was moderate and maximum visibility was approximately 10 nmi on both days. For these reasons, weather did not significantly impact on the interdiction operations. From the direction of Yerba Buena Island the target vessel was sometimes directly in front of the sun. The effect of the sun reflecting off the water and providing a bright light source directly behind the target degraded the ability to detect objects and personnel on the target vessel. All measurement instruments performed as expected.

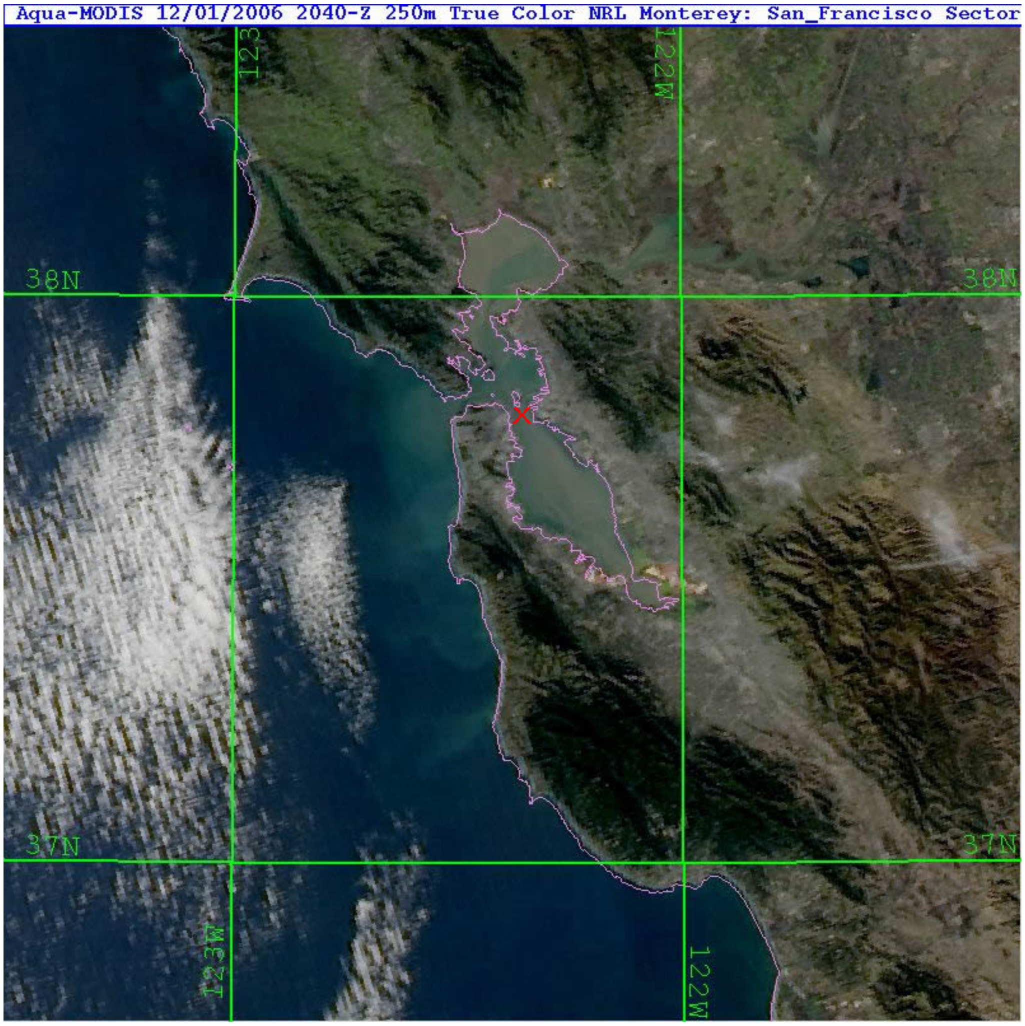

Figure 15 True color satellite image for 1240 PST 1 December, 2006 showing clear conditions in the San Francisco Bay with a few marine stratocumulus clouds outside the Golden Gate. The red X marks the region of the simulated interdiction operation.

2. TNT07-2 MIO

The main field program occurred on two days 20-21 March, 2007. On these days winds were light in the morning and picked up to about 15 kts in the afternoons. All operations occurred within the San Francisco bay and the small waves generated by the afternoon wind had little impact on operations. Skies remained overcast throughout the period and conditions were hazy. At times the clouds were low enough to obscure the tops of the higher buildings and bridges however near surface visibility ranged from 3 nmi to 8 nmi. Because the Sheriffs vessel was closer to the target vessel for virtually the entire time, the haze did not have significant effects on target detection. However the overcast conditions did cause less illumination of the target, thus limiting the ability to visibly detect smaller features, especially when they had dark backgrounds. All measurement instruments performed as expected.

3. TNT07-3 MIO

The main field program occurred on 5-6 June, 2007. This was the first MIO where operations occurred outside the Golden Gate. This was also the first time during a TNT MIO Project that Dr. Guest provided short weather briefs (on the mornings of 5 June and 6 June). The big weather story was the high winds in the Golden Gate region. On 5 June, sustained winds just outside the Golden Gate Bridge were in the 30- 35 knot range with at least one gust over 42 knots according to the in situ measurements onboard the ACSB. On 6 June the winds were somewhat less, but still significant enough to have a big impact on operations. Transferring personnel between vessels was difficult in these conditions. For this reason, the vessel personnel transfers on 6 June occurred inside the Golden Gate Bridge. In an actual terrorist situation, these high winds and associated high seas would have a great impact on operations and would make boarding a hostile vessel by boat or helicopter difficult. High winds are a common summer sea breeze and winter storm feature in the Golden Gate as the air flow is funneled through. Further out to sea or in the bay the wind speed is usually less.

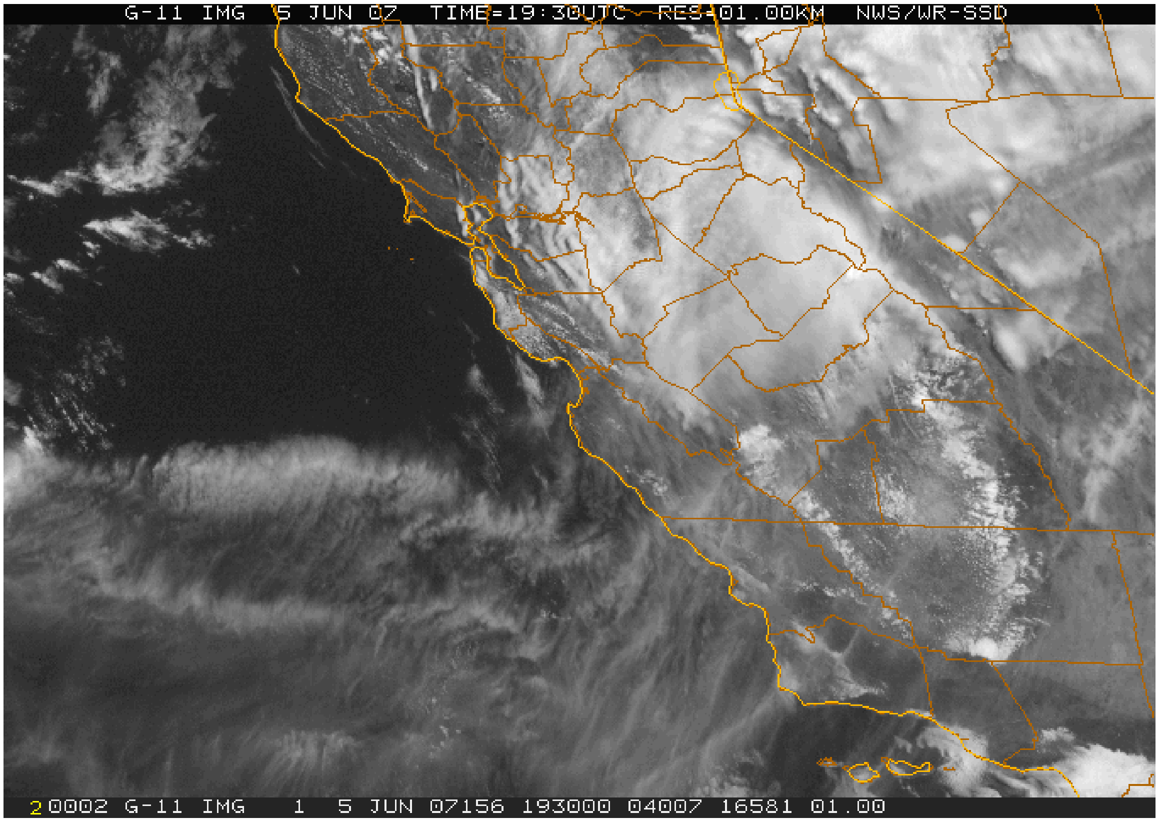

Figure 16 Visible channel image from the GOES satellite at 1230 PDT 5 June, 2007.

Visibility conditions were generally good; fog was not an issue and sky conditions were partly cloudy (Figure 16). There was some haze generated by sea spray and urban pollution, but it did not significantly impact on the visibility at the relatively close ranges between the Sheriff’s vessel and the target vessel. The most significant factor affecting the ability to detect features on the target vessel was the rocking motion of the sheriff’s vessel. Sea conditions just outside the Golden Gate can be very rough, especially when high winds meet an ebb tide. Observations of a buoy that was further out (~8 km range) indicated that optical turbulence was affecting the visibility at these ranges. The image was shimmering and showing obvious effects of turbulence. This is the first time significant optical turbulence effects have been noted during a TNT MIO and were related to the high winds that were observed. Unfortunately the compass (which was built into the sonic anemometer on the met station) failed at some time during the day on 5 June, 2007 and this caused problems with the true wind speed and direction calculations. This problem had occurred for other projects the authors have been involved with so we decided to use a different wind measurement system for future TNT experiments.

4. TNT07-4 MIO

Our measurements occurred 12 – 13 September, 2007. As with the previous TNT MIO, this exercise involved a simulated marine interdiction approximately 1 nmi outside the Golden Gate bridge. On 12 September there was a thick marine stratus that persisted all day (Figure 17), obscuring the top of the towers on the bridges. Conditions at the surface were hazy, but below the clouds, allowing a maximum visibility of approximately 15 nmi. The overcast conditions made target features a little more difficult to detect. Winds were from the west at about 12 kts. The sea swell outside the Golden Gate was relatively small, just 1 -2 ft. These conditions did not have a significant impact on the boarding operations. Later in the afternoon, after the experiment had completed, the winds in the Golden Gate picked up substantially, reaching speeds of 30 -35 kts (Figure 18). Had these winds occurred earlier, there would have been significant impacts on operations.

The next day, 13 September, the marine layer was not as thick and by 1300 PDT conditions were partly cloudy. Often strong winds are associated with the marine stratus burn-off. Therefore, based on the weaker marine layer that was likely to burn-off Dr. Guest forecast 30 kt winds in the Golden Gate region, in line with weather service forecasts. Fortunately although marine layer clouds did burn off, the high winds never materialized and remained around 6 kts for most of the day until a 14 kts sea breeze kicked in at 1140 at the measurement location just outside the Golden Gate (Figure 19). Making wind forecasts for the Golden Gate remains a challenging task.

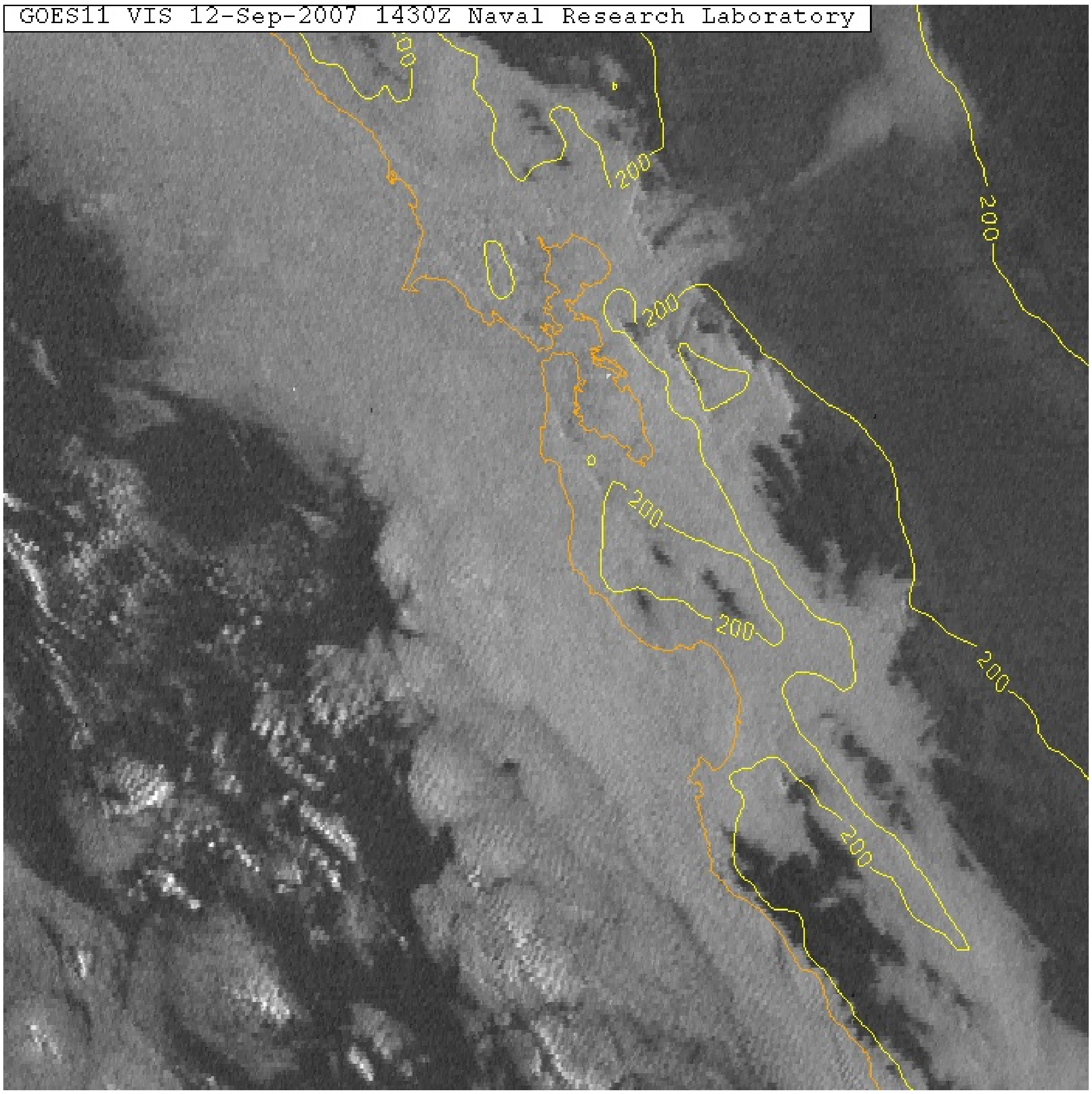

Figure 17 Visible channel image from the GOES satellite at 0730 PDT 12 September, 2007. Note the extensive cloud cover in the San Francisco Bay area.

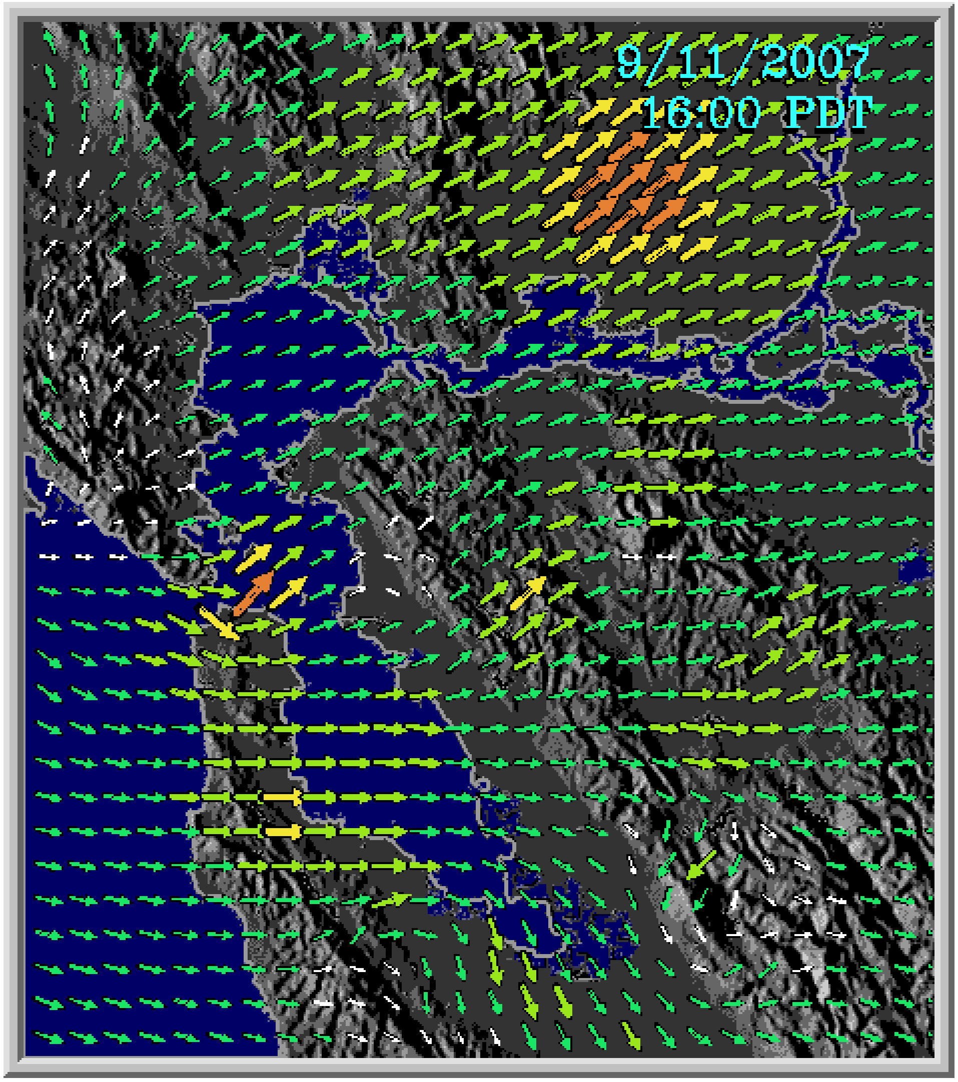

Figure 18. Wind vector diagram for the San Francisco bay area provided by the US Coast Guard. Orange indicates winds in the 20 -25 kts range. Note the strong localized winds in the Golden Gate; this is a common summer feature and its possible occurrence should be considered for any marine operations in this particular area. When high winds are combined with large ocean swell and an ebb tide, conditions can be treacherous for small vessels and boarding operations would be extremely difficult.

Visibility conditions were excellent on this day and the weather did not have significant impact on operations. All our measurement instruments performed as planned.

We also examined conditions in the New York Harbor region because TNT collaborators were performing exercises there also. On 11 September and intense band of showers passed through the area, but during the main exercises on 12 and 13 September, conditions were sunny and winds generally light, so there were no major weather impacts on operations there, although a hypothetical toxic plume would have been carried over densely populated areas.

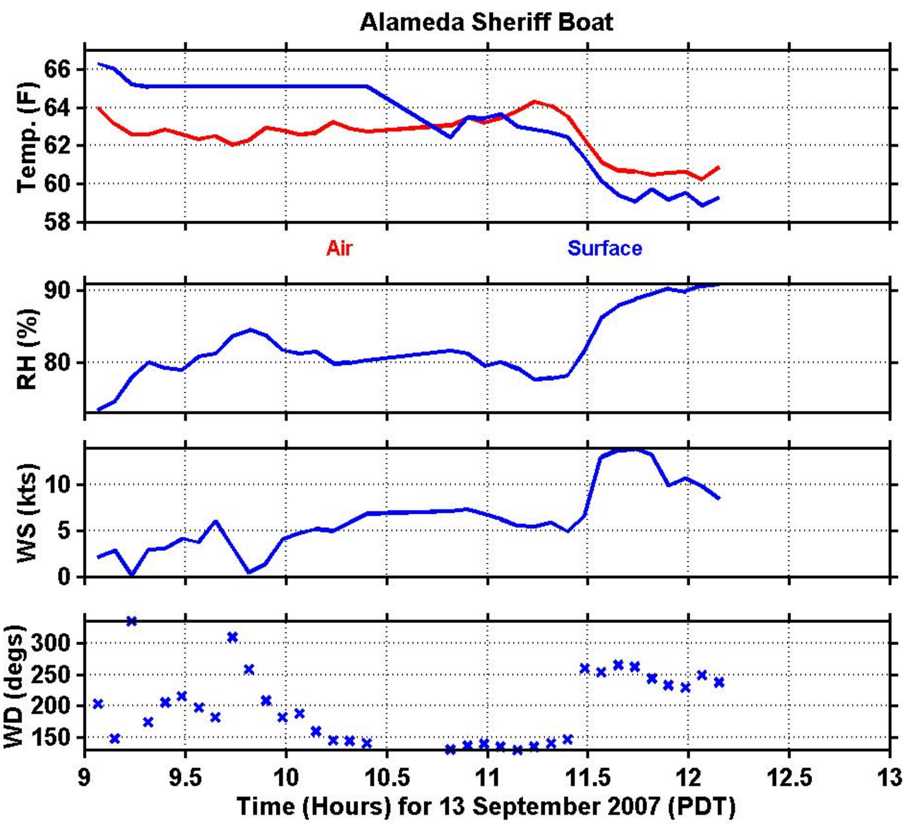

Figure 19 Meteorological conditions as measured on the Alameda County Sheriff's boat on 13 September, 2007. This is an example of the product that was put on the TNT network via Groove for every each day of the main experimental operations for all FY 2007 TNT MIOs.

C. VISIBILITY PREDICTIONS AND OBSERVATIONS

1. Visibility Predictions

Using the NPSVIZ model, a product similar to Figure 11 was successfully produced every day during the FY TNT MIO main operations. The NPSVIZ model predicted the visibility of the target boat, a person and a weapon (rifle). At no time did atmospheric conditions such as fog significantly affect the MIO operations, although there were some days when fog was close. These predictions are compared with actual observations later in this section.

The TAWS model was ran in the morning for each of the TNT MIO main operational days using the expected meteorological conditions as input. Two runs were performed, one for visible and one for IR detection of the target vessel. During the TNT 07-1 and TNT 07-2 exercises the model under predicted the ranges by a factor of almost 10. Noting this problem, we enlisted the help of Capt. Drew Frey, USAF, who is a TAWS expert. He helped us set up the model to produce realistic results, an example is shown in Figure 12. . The targets used for TAWS were the entire target vessels. The program has some kinds of vessels in its data base, but not ones identical to those used during the TNT MIOs. We assumed a "90 ft fishing Boat" for the target. In reality the target vessels were larger so the ranges were slightly under predicted. In the future we plan to transition to a more recent version of the model that has more target vessels in its data base.

2. Visibility Observations

Dr. Guest, on the boarding vessel, observed various features on the target vessel using naked eyes and binoculars and at different ranges. This was performed during all the TNT MIO periods for a variety of targets as described in Section II. A. 3. The maximum detectable range of each object was compared to the NPSVIZ model prediction of maximum detection range (Figure 20). The data from all the observations shows a reasonable agreement with the NPSVIZ predictions except for the gyro-stabilized binoculars which had larger feature detection ranges than predicted. The tuning of the

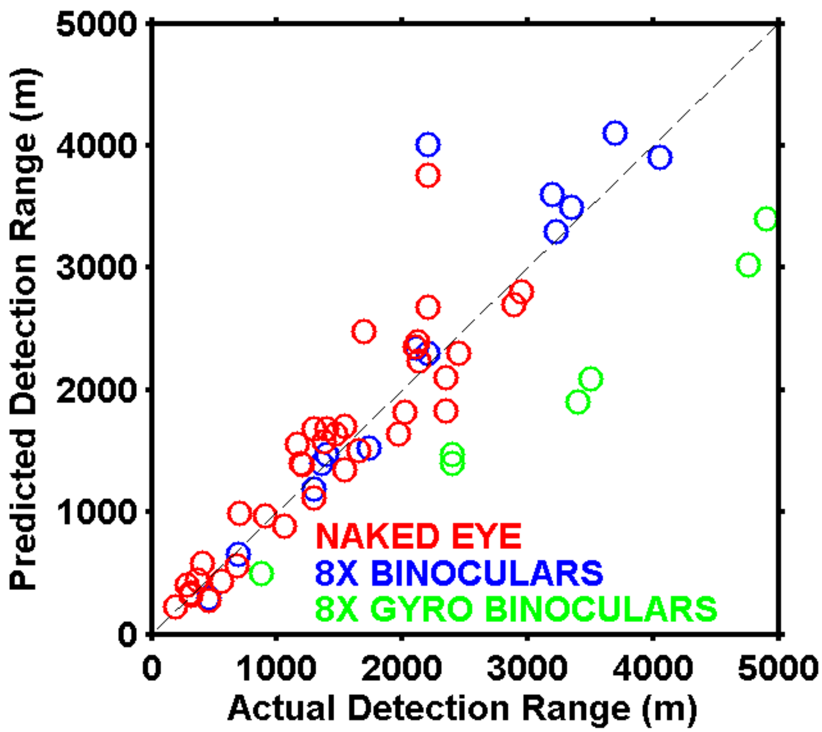

Figure 20 Comparison of predicted (NPSVIZ model) visible detection ranges with observed detection ranges for various size target features.

NPSVIZ model for gyro-binoculars prior to these results was based on only one observation, so it is not surprising there was a bias error. The errors in prediction range (i.e. scatter from the perfect fit line in Figure 20) were generally proportional to range.

The errors were therefore quantified by calculating the logs of the data and then determining the standard deviation in log space and converting this back to a percentage. The naked eye predictions had a standard deviation of 28% while the normal binoculars varied by 34%. These errors were the result of many factors, including varying illumination conditions, different backgrounds and varying ship motion (the latter especially for the normal binoculars). All these observations were performed by Dr. Guest who has close to 20/20 vision. Other observers would likely have different results. The size of various features (see Table 2) often had to be estimated rather than directly measured; this introduced error in the predictions. The target vessels were relatively close and visibility was not greatly impacted by extinction or optical turbulence at these ranges, this characteristic was correctly modeled by NPSVIZ.

Future versions of the NPSVIZ model will take into account as many of the above factors as possible. We plan to place more reliance on photographs in the future to allow more quantitative assessment of lighting and background effects.

D. RADAR RANGE PREDICTIONS

AREPS model runs were successfully performed each day using the 0500 PDT Oakland radiosonde data to specify the atmospheric profiles (Figure 21). For the first three FY2007 MIOs this was done at NPS by Ms. Jordan while for the last exercise Dr. Guest ran the model in the mornings on his laptop. The resulting products included ranges along bearings (see Figure 14) as well as probability of detection range/height cross sections (see Figure 13). For operations within the SF bay , the topography of the land around SF Bay was the dominant factor limiting radar range. Outside the Golden gate, the seaward radar ranges were unobstructed by topography, therefore atmospheric influences were potentially important. Even though radar ducting conditions are common during the summer in the San Francisco (SF) Bay region, none happened to occur during any of the FY 2007 TNT MIOs. There were some variations in refractive conditions and maximum ranges for a 12 ft high X-band radar ranged from 9.8 to 12.7 nmi.

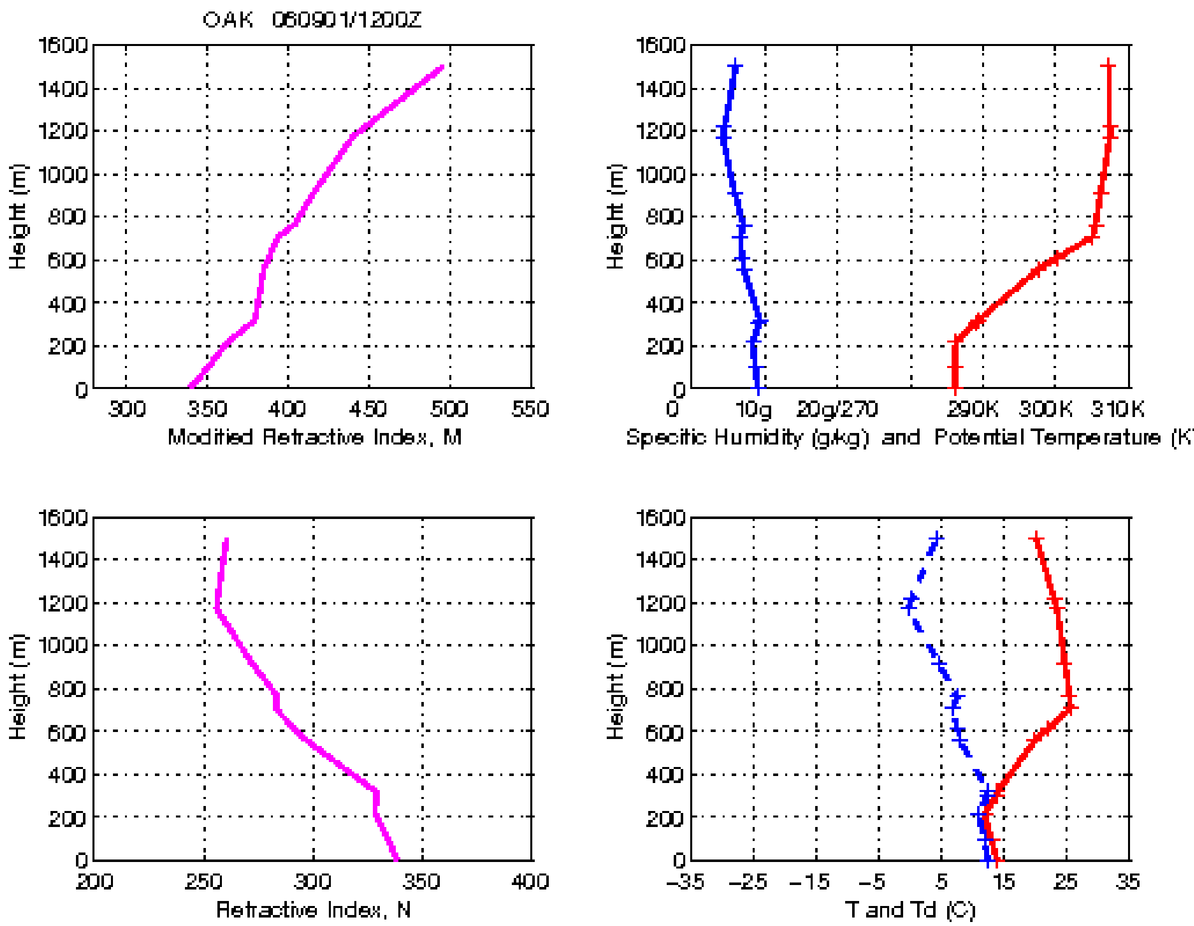

Figure 21. Example of profiles of atmospheric and refraction parameters from the 0500 PDT Oakland radiosonde. A similar plot was produced each day. This allows the easy detection of ducts and other refractive features.

During TNT 07-4 MIO radar ranges predictions were performed for a vessel just outside New York Harbor and posted on Groove is support of our collaborators (Figure 22.) No ducts existed and radar ranges were normal.

For all the FY 2007 TNT MIO experiments, the target vessel was always well within the radar range of the boarding vessel so we were not able to verify predictions of radar range using the “official” target vessel.

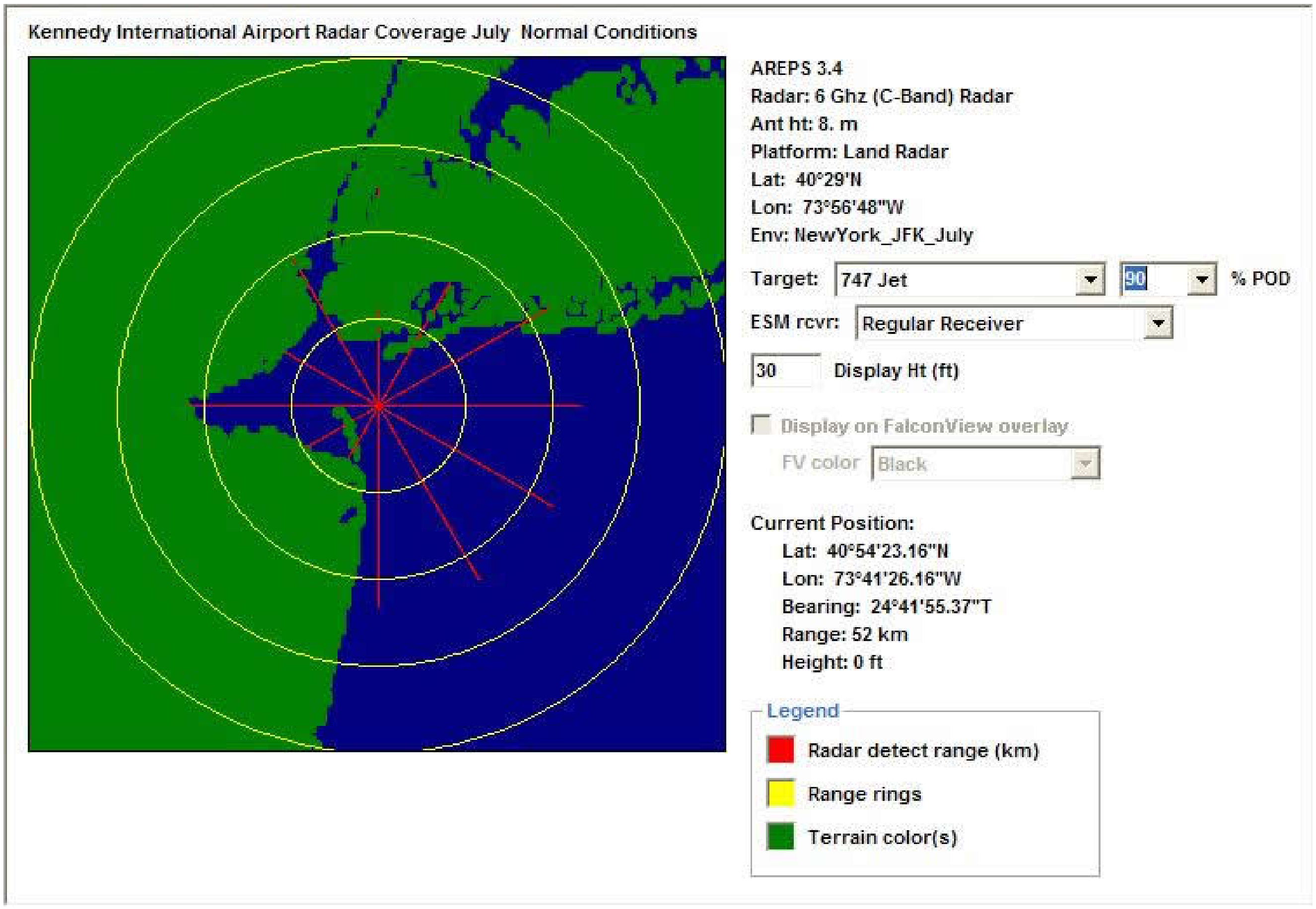

Figure 22. AREPS predictions of radar range for 12 September, 2007. Each red spoke represents the predicted 90% probability of detection along that particular bearing.

E. TNT NETWORKING

A primary goal of our effort was to test and demonstrate the ability of using the TNT networked system to relay atmospheric information between command centers, model prediction centers and field personnel. In order to best characterize the environmental aspect of situational awareness, information sources must include local *in situ* measurements and observations by field personnel as well as the rich variety of products available from “outside sources.” These outside sources include the National Weather Service, Fleet Numerical Meteorology and Oceanography Center, the Air Force Weather Agency, other government agencies, academic institutions and commercial research and media companies. These sources provide two types of products, current observations and model predictions of future conditions. In some cases the outside products are improved by information from the inside. For example an *in situ* measurement system on an interdiction vessel could be used as input into a prediction model that exists outside of the immediate networked system and the results then fed back into the field on a timely basis. This type of procedure is already used by US military forces for many weather-related products. However it has not been fully implemented in the TNT context.

For the FY 2007 TNT MIOs, we developed tools and processes for prediction of target detection characteristics using both inside (*in situ*) and outside sources of information. One of the challenges for TNT was to refine and process this large variety of information in a way that provides the end user on the ground or in a control center with a product that provides just the necessary information that is required without extraneous detail.

We were able to use the Groove software and the TNT network system to provide a variety of products and transmit information both ways to and from the field and to

NPS and all the other locations served by the TNT network. These products were organized in a simple file hierarchy.

The TNT network to the vessel and also at time to NPS was not always operational, therefore we sometimes were not able to make the products available in real time. However the reliability generally improved for each subsequent exercise.

To conclude our discussion of network issues, we demonstrated in this field program that a variety of products could be transmitted throughout the TNT network and made available to distant command and planning centers as well as the people in the field. However there are many ways this process could be made more efficient and useful.

F. RESULTS OF INTERVIEWS WITH FIELD PERSONNEL

The field program gave Dr. Guest the opportunity to discuss target detection issues with the operators of the boarding vessel, who were Alameda County Sheriff deputies and also other personnel involved in the boarding operations. The authors believe that even though we may be considered experts on target detection issues, getting feedback from the personnel performing the operations is invaluable.

Fog and haze are common in the SF Bay and this was often noted as the limiting factor of visible detection of targets. Knowledge of where fog is present for a particular day and if and when it will burn off is a crucial factor in mission planning. The Golden Gate region is particularly susceptible to decreased visibility due to the increased winds that advect fog from the open sea through this region. The Alameda County Sheriffs mentioned the importance of target illumination and background (contrast) for visible target detection. They also noted differences in target detection capabilities among different people due to varying eyesight quality and experience.

Concerning radar, they noted that conditions changed from day to day, but did not relate this to atmospheric effects. They could not associate changes in radar characteristics to specific weather conditions. This may be due, at least in part, to the short ranges encountered within the bay, as discussed earlier. The most important reason for changes in radar detection cited by the ship's skipper was when different settings were used. Human issues are important factors related to the effectiveness of radar.

It may be that environmental issues are involved in this type of human issue. For example if there is a strong evaporation duct, radar clutter will be an issue and the operator may turn down the sensitivity. A few hours later or the next day, the evaporation duct may be weaker, clutter is less of an issue and optimum performance would be with a higher sensitivity setting. A different operator at this time would blame the previous operator for turning down the sensitivity too much.

IV. LESSONS LEARNED

Unlike previous years, the authors have put more emphasis on how the environment affects all aspects of the MIO operations besides just target detection. Sea state and fog were the most apparent environmental effects that affected the FY2007 TNT MIO projects. The rough conditions that often exist just outside the Golden Gate Bridge can have a big impact on boarding operations, especially for smaller vessels. There is certainly room for improvement in the forecasts of these conditions. We plan to incorporate more fine resolution mesoscale atmospheric models to aid this effort.

Ocean swell was not an important factor during the TNT07-3 and TNT07-4 experiments. However, during the next MIO, which will occur in the winter, it is likely that ocean swell will be greater due to the presence of storms. Predicting the interaction between tides, swell and winds in the Golden Gate area and how they will affect boarding operations will be a challenge.

The NPSVIZ model showed skill in predicting detection ranges, but there were still errors due to a variety of factors. Improvement in the accuracy will require inclusion of factors such as target illumination, background contrast and motion of the observer (ship rocking). The TAWS model needs to have targets in its data base that are closer to the targets in the TNT MIO exercises. We will work with the developers of the model to include such targets. A more difficult challenge is modeling human factors such as eyesight acuity, experience and motivation which are not contained in either of these two models.

Due the short ranges involved, we were not able to perform and radar range detection model verifications during the FY2007 TNT MIOs. It would be impractical for the MIO target vessels to go far enough out (> 15 nmi) to sea to test the radar range predictions. In the future, we plan to use targets of opportunity (vessels entering the SF bay from far out at sea) rather than the "official" MIO target vessels to test target range predictions.

V. CONCLUSIONS

Considerable progress was made toward meeting the goals stated in the introduction during FY2007. We have developed a system that allows the incorporation of a variety of data sources in support of MIO operations. We also acquired much data that allowed us to tune and verify the three target detection models that we used. We learned much about the reliability of standard forecast products for predicting environmental conditions in the SF Bay area, particularly with respect to fog and wind conditions. We also continued to increase out understanding of how non-atmospheric factors such as human, platform and viewing instrument characteristics affect target detection. With more experience and data collection, we believe more progress can be made in the future toward meeting our goals and supporting MIO operations.

APPENDIX
Background information on radar and optical target detection

The radar detection range is affected by the temperature and humidity structure of the atmosphere. When the atmosphere causes the radiation to bend back down toward the Earth's surface, a "duct" is said to occur. If both transmitter and target (or receiver) are within a duct, greatly extended ranges exist. There are two types of ducts which affect propagation between vessels: (1) a "surface duct" which is generally caused by a sharp decrease in humidity, and to a lesser degree an increase in temperature (inversion) that often occurs at the top of the atmospheric boundary layer (the turbulent part of the atmosphere that directly interacts with the surface) and (2) and an "evaporation duct" which is caused by surface evaporation. Note the evaporation duct causes ducting at the surface but since it is distinguished from (1) due to its different effects and formation mechanisms. Quantifying the surface duct requires some type if upper air measurement using radiosondes (weather balloons) or aircraft while the evaporation duct can be estimated using measurements near the surface. Surface ducts extend several hundred meters up into the atmosphere and don't have much effect at ranges less than approximately 20 kilometers. Evaporation ducts are usually 20 meters or lower above the surface and affect ranges as close as a few hundred meters. Surface ducts typically affect all UHF, VHF and microwave frequencies while evaporation ducts only affect microwave frequencies.

Visible and infrared (electro-optical or EO) radiation and hence visible target detection ranges are affected by (1) turbulent fluctuations in temperature and humidity ("optical turbulence"), (2) suspended particles in the atmosphere ("aerosols") such as dust, sea spray and pollution, (3) cloud and fog droplets and (4) hydrometeors (rain, snow, sleet etc.). Detection of the radio (EM) and optical/IR (EO) wavelengths are also affected by a variety of non-atmospheric factors, many of which are discussed in the report.

REFERENCE

Guest, P., K. Davidson, M. Jordan, and R. Lind, 2007: TNT06-4 MIO San Francisco Bay, Atmospheric Effects After Action Report, **NPS-MR-07-001**, 7 March.

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